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(54) **MECHA-HYDRAULIC ACTUATED INLET CONTROL VALVE**

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(Continued)

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(Continued)

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(Continued)

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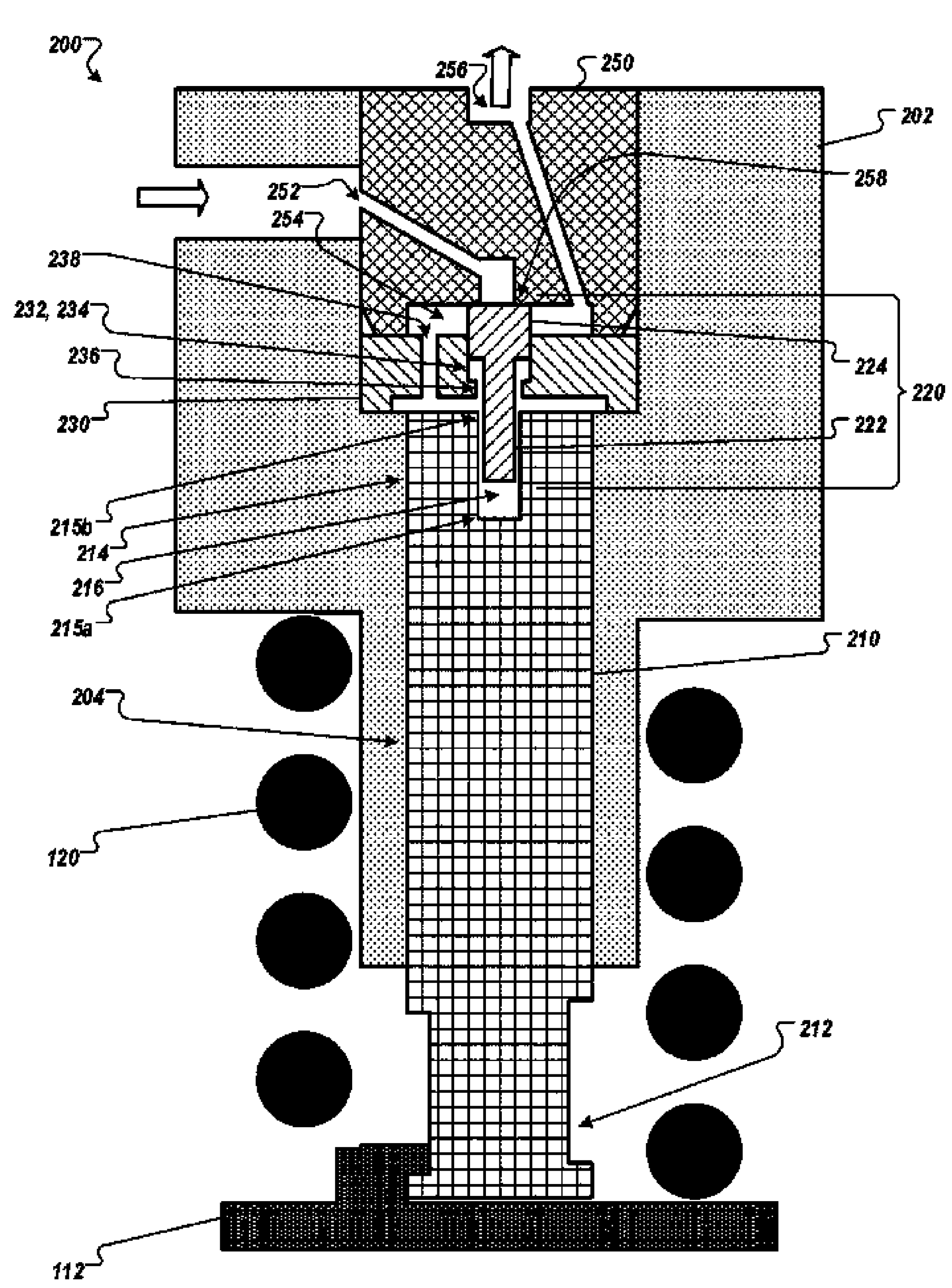
(57) **ABSTRACT**

The subject matter of this specification can be embodied in, among other things, a fluid control device that includes a housing defining a plunger cavity in fluid communication with a fluid inlet and a fluid outlet, a valve having a shaft having a first end and a second end, and a stopper at the first end configured to block a fluid circuit between the fluid inlet and the fluid outlet in a first configuration of the inlet control valve and connect the fluid circuit in a second configuration of the inlet control valve, and a plunger configured for axial movement within the plunger cavity, defining a shaft cavity having an inner wall extending from an enclosed end to an open end in fluid communication with the fluid outlet, and configured to accommodate axial movement of the shaft within the shaft cavity.

23 Claims, 8 Drawing Sheets



(51) **Int. Cl.**

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F02M 41/04	(2006.01)
F02M 59/02	(2006.01)
F02M 59/10	(2006.01)
F04B 7/02	(2006.01)

(52) **U.S. Cl.**
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(58) **Field of Classification Search**
USPC 123/357, 385, 387, 495, 496, 506; 137/87.03, 503
See application file for complete search history.

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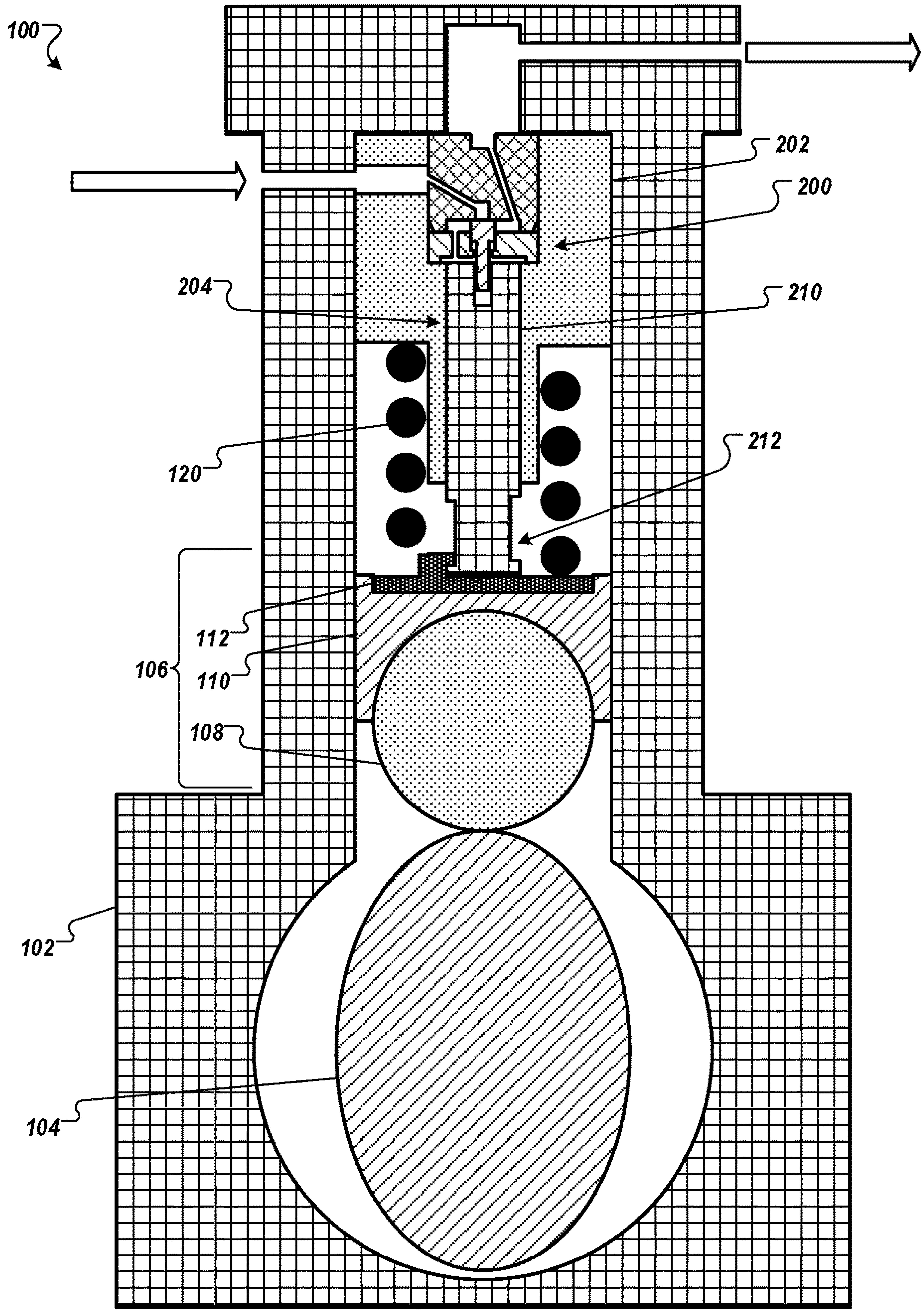
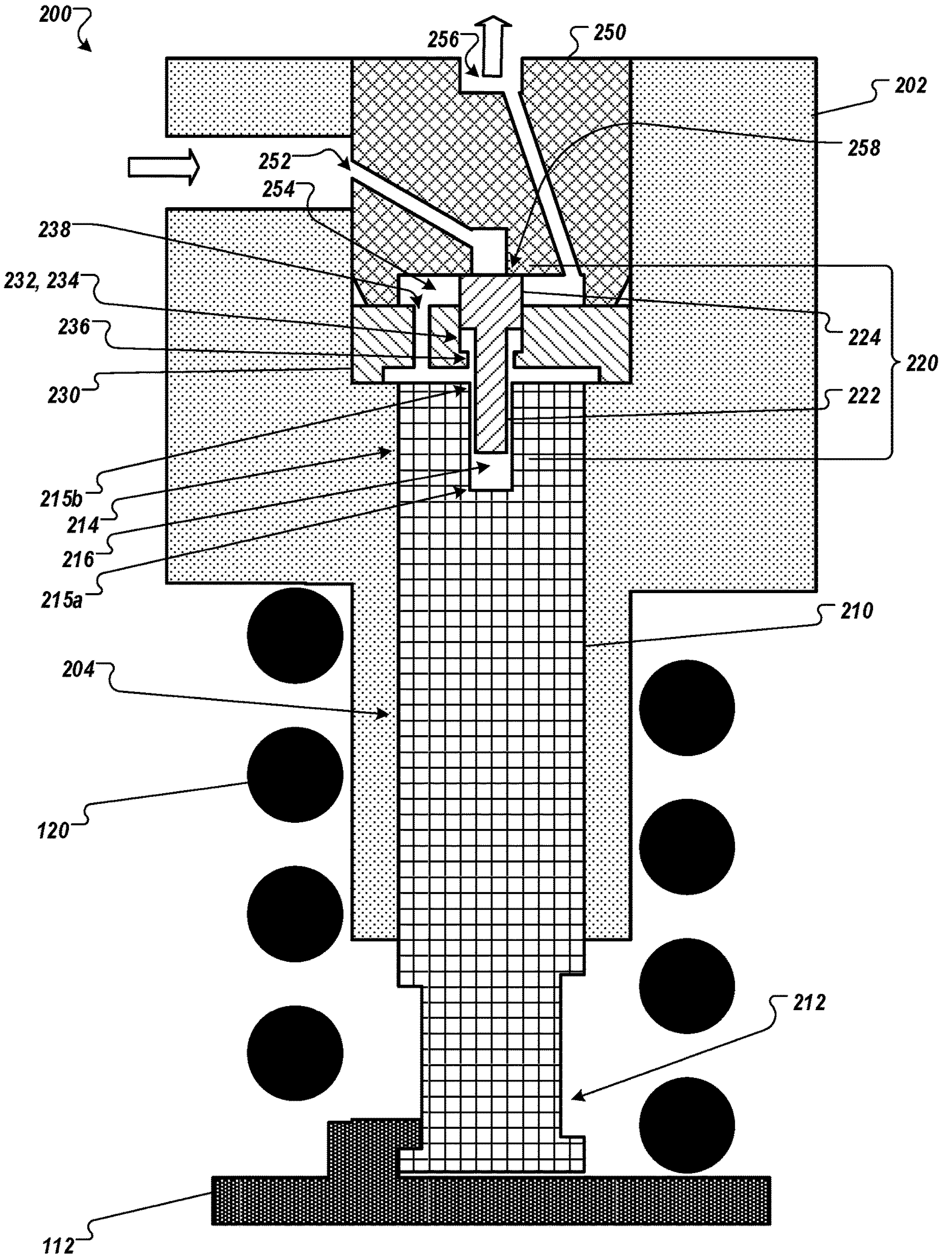


FIG. 1



200
256
250
202
258
252
254
238
232, 234
224
236
220
230
222
215b
214
216
215a
210
204
120
212
112

FIG. 2

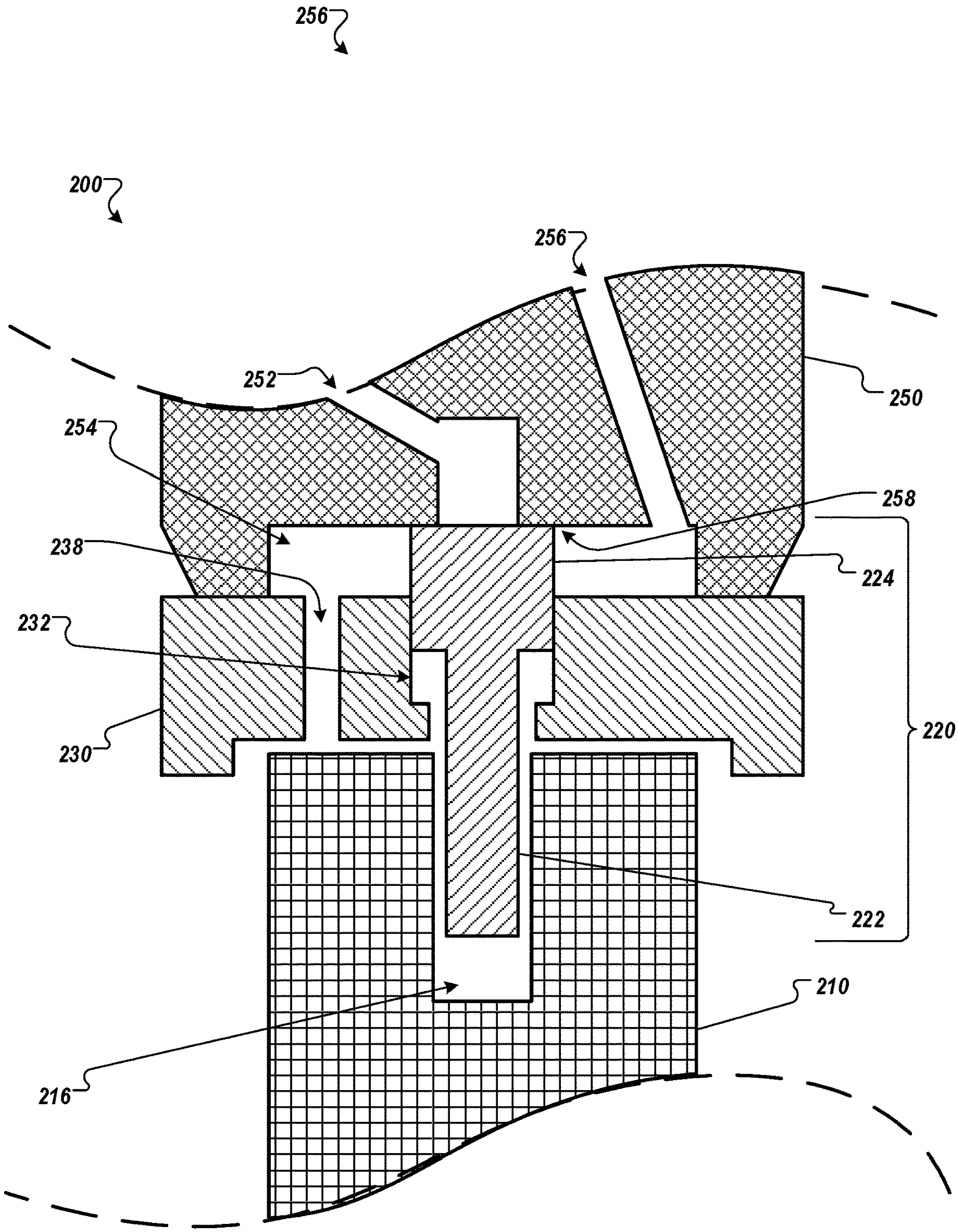


FIG. 3A

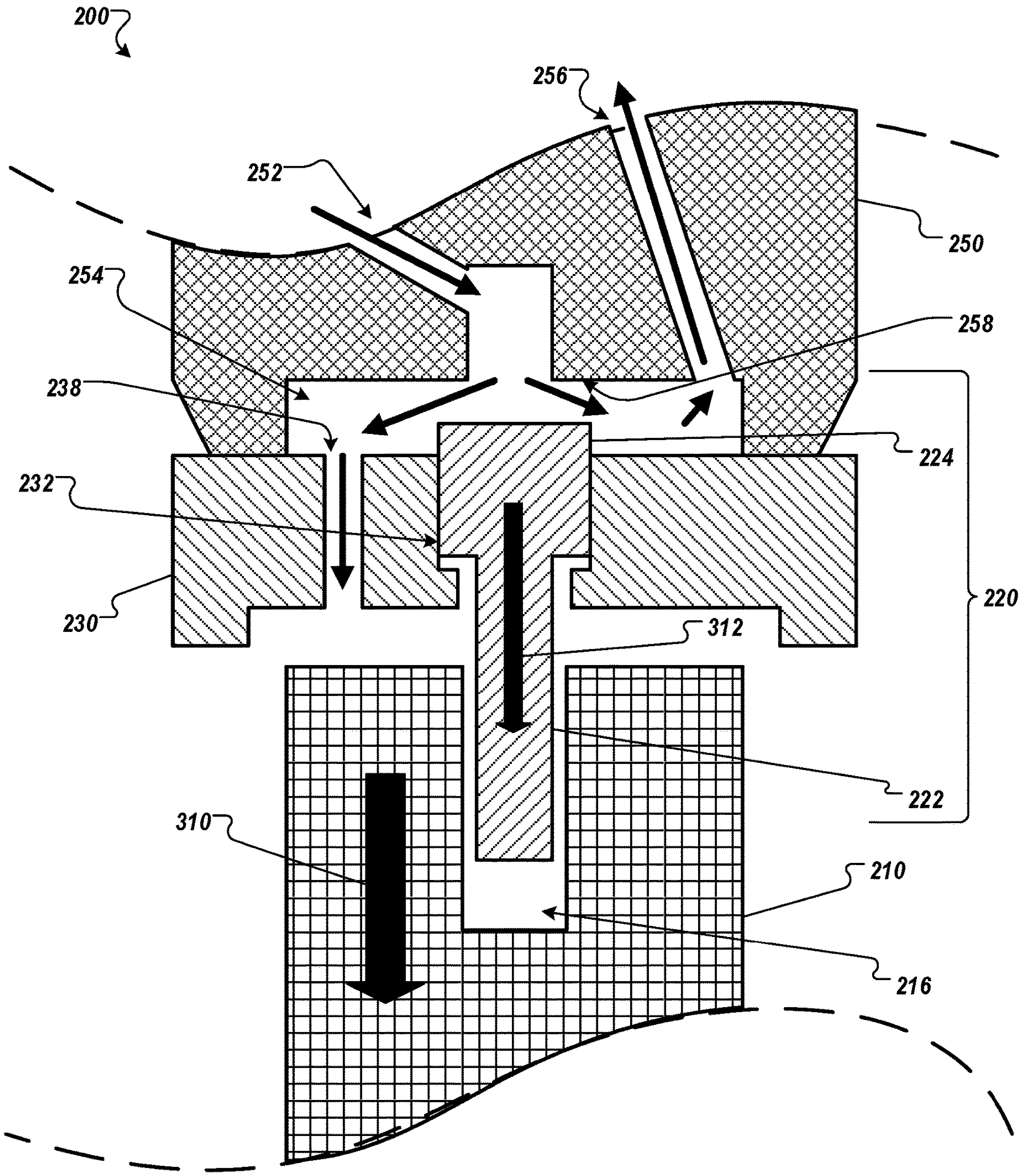


FIG. 3B

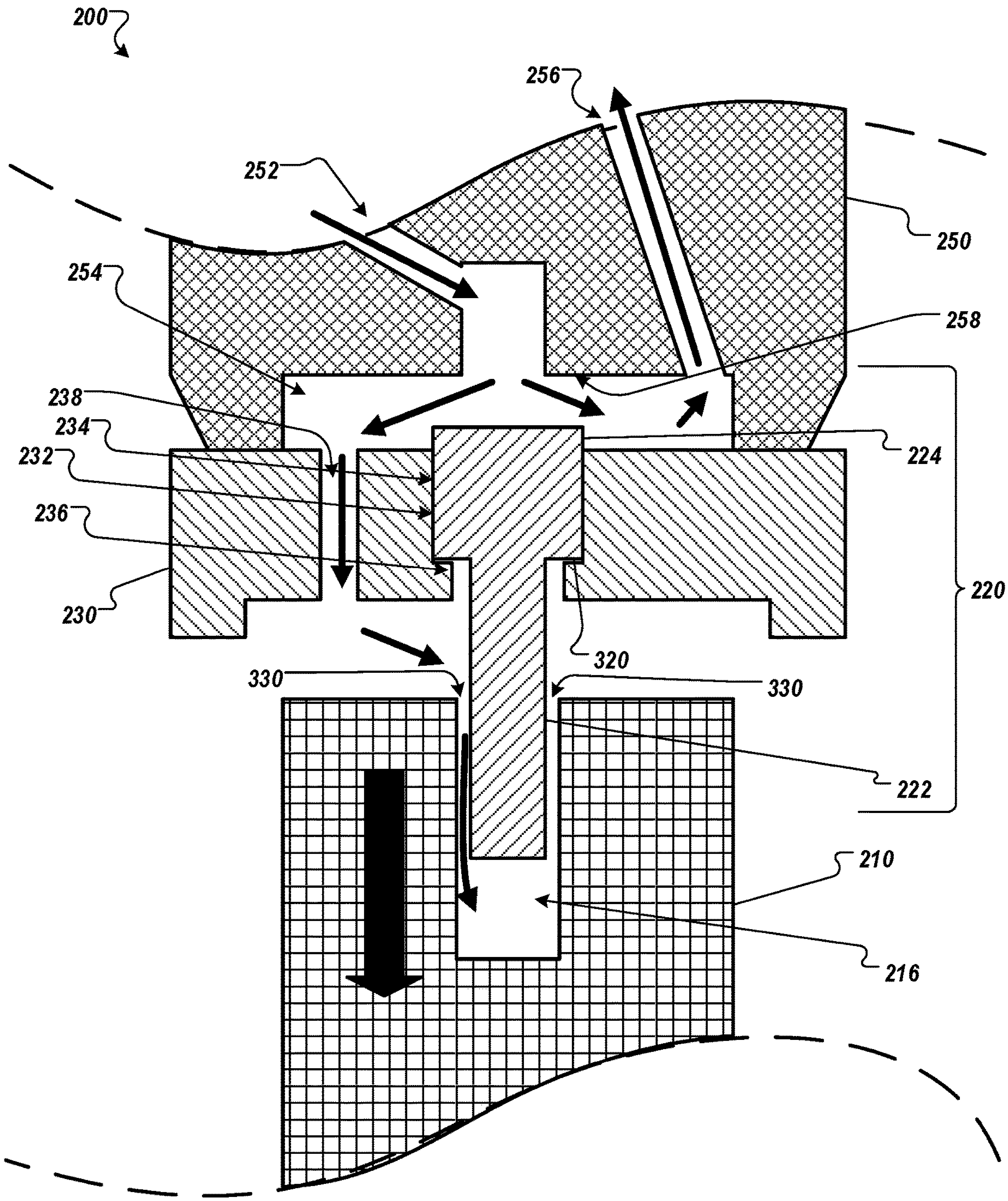

200
256
252
250
254
258
238
234
224
232
236
220
230
320
330
330
222
210
216

FIG. 3C

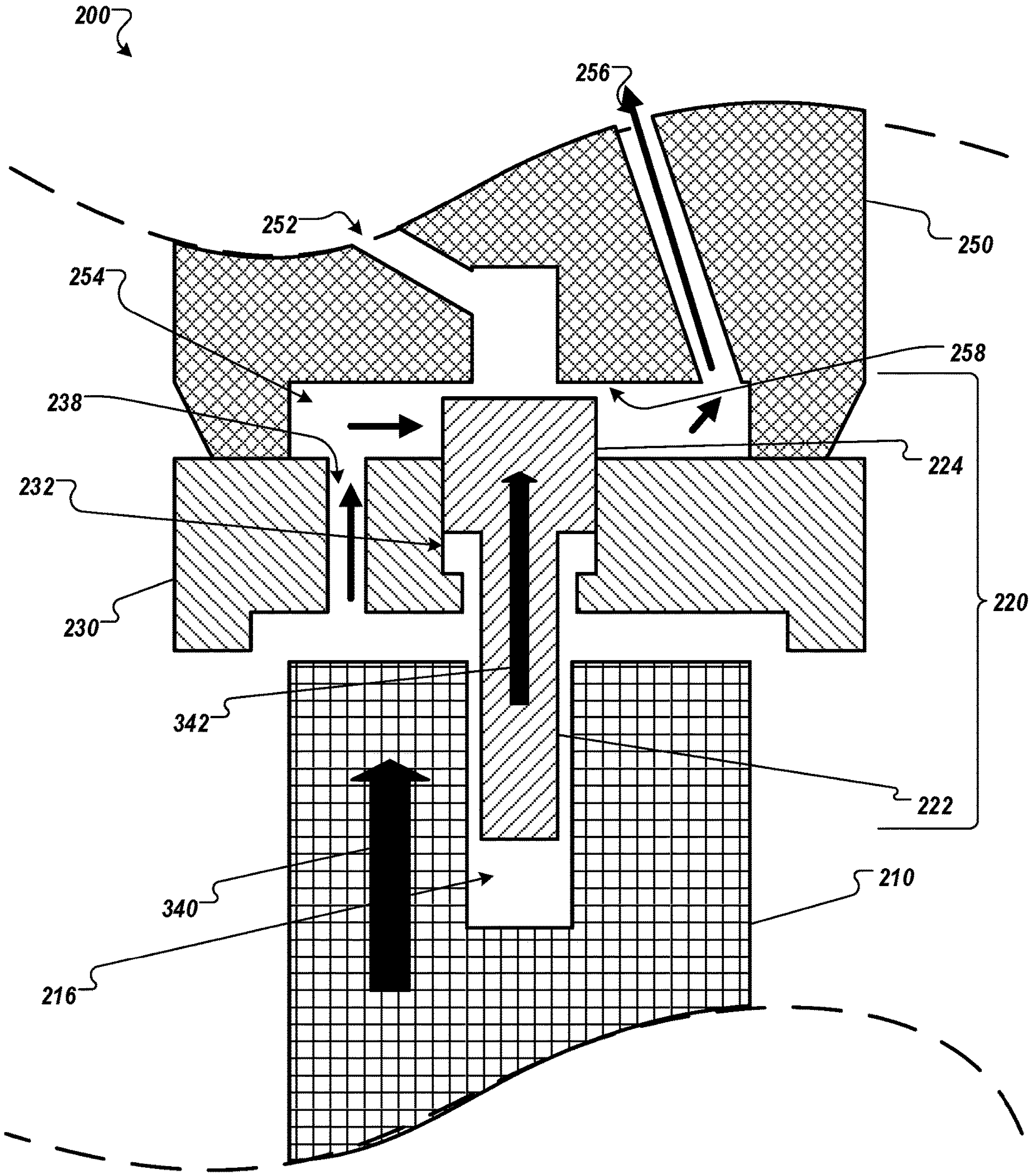


FIG. 3D

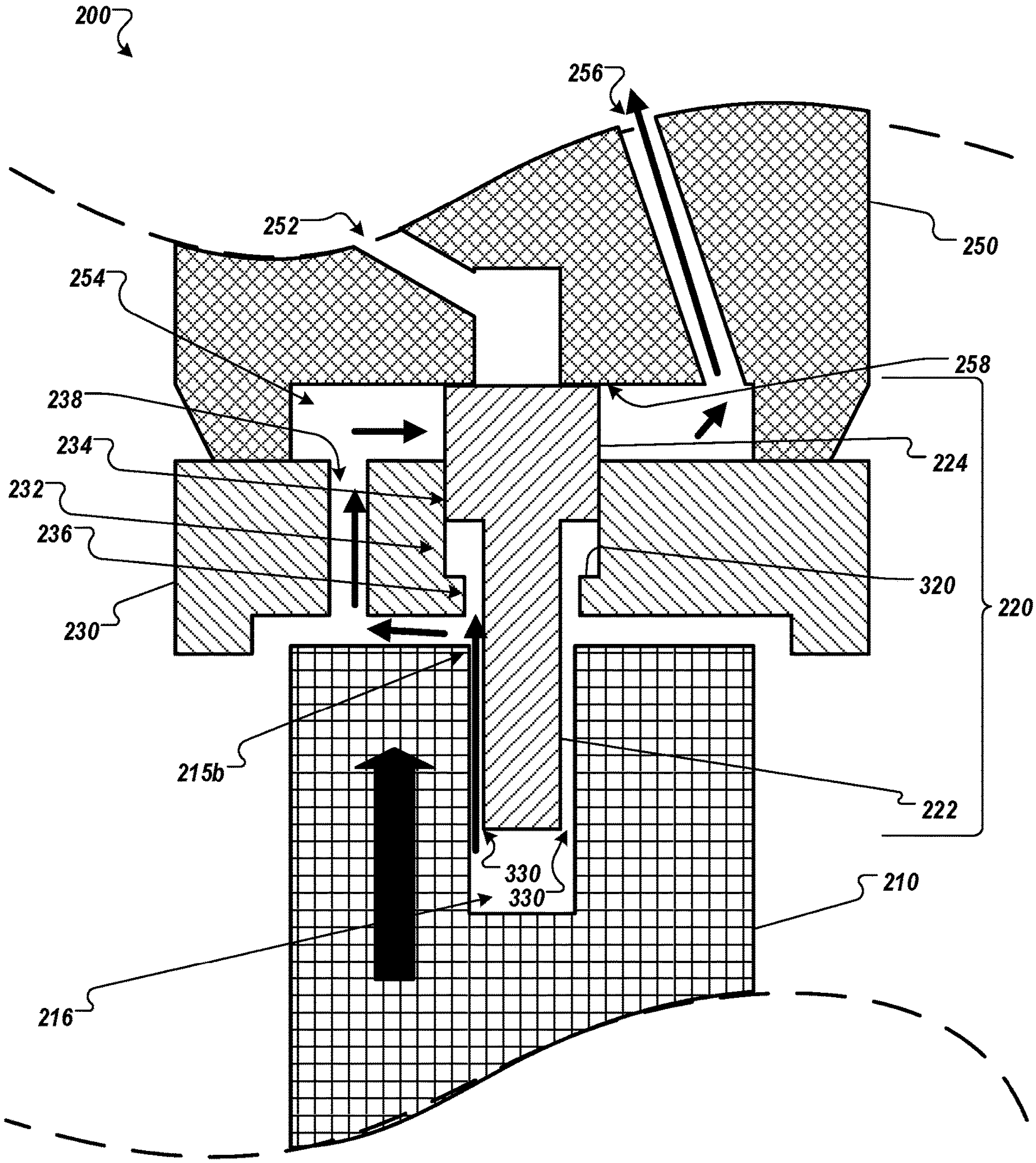

200
256
252
250
254
258
238
224
234
232
236
320
220
230
215b
222
330
330
210
216

FIG. 3E

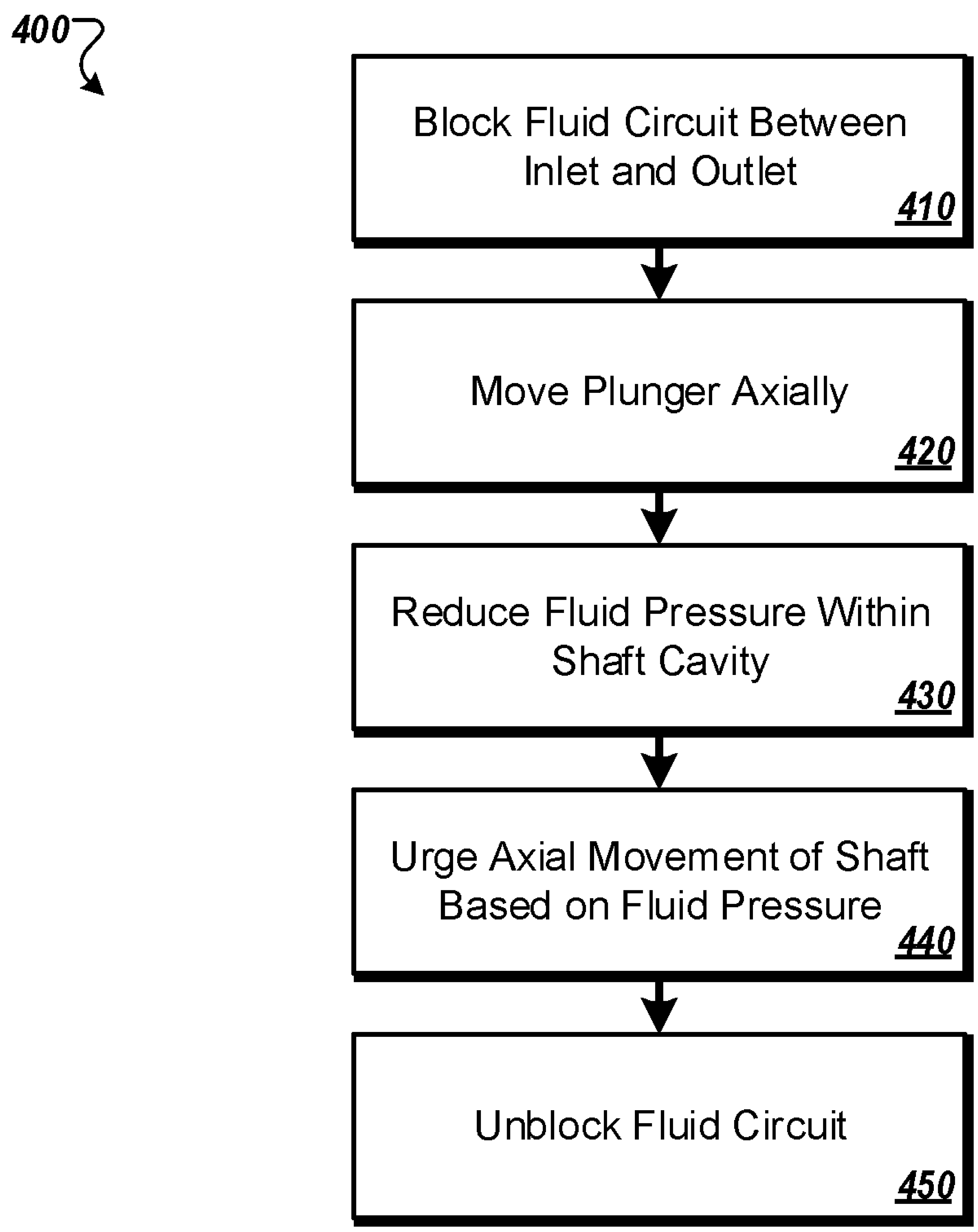

400
Block Fluid Circuit Between Inlet and Outlet
410
Move Plunger Axially
420
Reduce Fluid Pressure Within Shaft Cavity
430
Urge Axial Movement of Shaft Based on Fluid Pressure
440
Unblock Fluid Circuit
450

FIG. 4

MECHA-HYDRAULIC ACTUATED INLET CONTROL VALVE

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims the benefit of priority to U.S. Provisional Patent Application Ser. No. 62/526,880, filed on Jun. 29, 2017, the contents of which are hereby incorporated by reference.

TECHNICAL FIELD

This instant specification relates to fluid control valves, more particularly, fluid-dampened inlet control valves.

BACKGROUND

In operation of a piston pump, an inlet control valve (ICV) opens a fuel inlet in the working volume during an intake stroke and resists a fuel back flow during a pump stroke. Accordingly, to achieve optimized flow efficiency the valve should open at the very beginning of the intake stroke and close at the end of the intake stroke (e.g., at the beginning of pumping stroke).

Some existing ICVs are designed to open at a predetermined pressure, sometimes referred to as a valve opening pressure (VOP), which is achieved by a spring that provides a defined amount of force. Thus, the opening of the valve is not directly dependent on valve movement (i.e., position), but rather on a fluid pressure in a pump element. Furthermore, these valves are designed to close when the pump stroke begins. In some prior designs, the closing of the valve is again driven by the pressure conditions in the pump element. Such techniques for controlling an ICV operation can lead to a number of unwanted problems, such as reduction in volumetric pump efficiency, slow ICV response, fluid cavitation (for example, due to slow response and/or backflow), and mechanical damage (e.g., caused by cavitation, valve bounce).

SUMMARY

In general, this document describes fluid control valves, more particularly, fluid-dampened inlet control valves.

In a first aspect, a fluid control device includes a housing defining a plunger cavity in fluid communication with a fluid inlet and a fluid outlet, a valve having a shaft having a first end and a second end, and a stopper at the first end configured to block a fluid circuit between the fluid inlet and the fluid outlet in a first configuration of the inlet control valve and connect the fluid circuit in a second configuration of the inlet control valve, and a plunger configured for axial movement within the plunger cavity, defining a shaft cavity having an inner wall extending from an enclosed end to an open end in fluid communication with the fluid outlet, and configured to accommodate axial movement of the shaft within the shaft cavity.

Various embodiments and include some, all, or none of the following features. The shaft and the inner wall can define a fluid passage from the open end to the enclosed end. The shaft cavity and the shaft can be configured such that the fluid passage has a predetermined cross-section. The fluid control device can include a biasing member configured to urge the valve toward the first configuration. The fluid control device can include a fluid seal between the plunger and a plunger cavity wall of the plunger cavity, wherein the

seal can define a portion of the plunger cavity. The fluid control device can include an actuator configured to urge movement of the inlet control valve between the first configuration and the second configuration. The actuator can include a cam follower coupled to the plunger and configured to urge reciprocal axial movement of the plunger in response to rotation of a cam. The actuator can include a linkage connected to a crankshaft. The actuator can be one of an electromagnetic solenoid, an electromagnetic servo, or an electromagnetic motor coupled to the plunger and configured to urge reciprocal axial movement of the plunger in response to an electrical activation signal.

In a second aspect, a method of fluid control includes blocking, by a stopper at a first end of a shaft of a valve, a fluid circuit between a fluid inlet to a fluid outlet, wherein the valve is at a first position, moving a plunger axially within a plunger cavity from a first plunger position toward a second plunger position, wherein the shaft is arranged within a shaft cavity defined within the plunger between an enclosed end and an open end, reducing, by movement of the plunger toward the second plunger position, fluid pressure of a fluid within the shaft cavity between the shaft and the plunger, urging, by the reduced fluid pressure, axial movement of the shaft within the shaft cavity from a first valve position toward a second valve position, and unblocking, by the stopper based on axial movement of the shaft, the fluid circuit.

Various implementations can include some, all, or none of the following features. The method can include flowing fluid from the open end toward the enclosed end between the shaft and an inner wall of the shaft cavity, restoring fluid pressure within the shaft cavity between the shaft and the plunger, and stopping movement of the shaft relative to the plunger. The method can include moving the plunger axially within the plunger cavity toward the first plunger position, increasing, by movement of the plunger toward the first position, fluid pressure within the shaft cavity between the shaft and the plunger, urging, by the increased fluid pressure, axial movement of the shaft within the shaft cavity toward the first valve position, and blocking, by the stopper, the fluid circuit. The method can include flowing fluid from the shaft cavity toward the open end between the shaft and an inner wall of the shaft cavity, restoring fluid pressure within the shaft cavity between the shaft and the plunger, and stopping movement of the shaft relative to the plunger. The method can include urging, by a biasing force provided by a compliant member, movement of the valve toward the first valve position, wherein the reduced fluid pressure is sufficient to overcome the biasing force.

In a third aspect, an engine system includes a combustion chamber, a camshaft, a fuel rail, and a fluid control device having a housing defining a fluid inlet in fluid communication with the fuel rail, a fluid outlet in fluid communication with the combustion chamber and the plunger cavity, a valve having a shaft having a first end and a second end, and a stopper at the first end, configured to substantially block fluid flow from the fluid inlet to the fluid outlet in a first configuration of the inlet control valve and allow fluid flow from the fluid inlet to the fluid outlet in a second configuration of the inlet control valve, and a plunger configured to follow the camshaft and move axially within the plunger cavity, the plunger defining a shaft cavity having an inner wall extending from an enclosed end to an open end in fluid communication with the fluid outlet, and configured to accommodate axial movement of the shaft within the shaft cavity.

Various embodiments can include some, all, or none of the following features. The shaft and the inner wall can define a fluid passage from the open end to the enclosed end. The shaft cavity and the shaft can be configured such that the fluid passage has a predetermined cross-section. The engine system can include a biasing member configured to urge the valve toward the first configuration. The engine system can include a fluid seal between the plunger and a plunger cavity wall of the plunger cavity, wherein the seal can define a portion of the plunger cavity. The engine system can include an actuator configured to urge movement of the inlet control valve between the first configuration and the second configuration. The actuator can include a cam follower coupled to the plunger and configured to urge reciprocal axial movement of the plunger in response to rotation of a cam. The actuator can include a linkage connected to a crankshaft. The actuator can be one of an electromagnetic solenoid, an electromagnetic servo, or an electromagnetic motor coupled to the plunger and configured to urge reciprocal axial movement of the plunger in response to an electrical activation signal.

The systems and techniques described here may provide one or more of the following advantages. First, an inlet control valve can open and close early in the intake and pump strokes. Second, the inlet control valve can increase the volumetric efficiency of the pump. Third, the inlet control valve can reduce the formation of cavitation bubbles.

The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

FIG. **1** is a cross-sectional diagram of an example of a system for fluid delivery that includes an example inlet control valve.

FIG. **2** is an enlarged cross-sectional diagram of the example inlet control valve of FIG. **1**.

FIGS. **3**A-**3**E are further enlarged cross-sectional diagrams of the example inlet control valve of FIGS. **1** and **2** at various stages of an operational cycle.

FIG. **4** is flow chart that shows an example of a process for controlling fluid flow using an example inlet control valve.

DETAILED DESCRIPTION

This document describes fluid control valves, more particularly, fluid-dampened inlet control valves (ICVs), and techniques for using such valves. In general, the operation of the ICVs described in this document are controlled through a fluid connection between the ICV and a plunger. Localized pressures developed by fluid encapsulated between the ICV and plunger and caused by relative motion of the ICV and plunger, as well as the transfer of motion between the ICV and plunger by viscous friction forces of the fluid, urge relative motion of the ICV and plunger. By means of this connection between the components, the timing of opening and closing events of an ICV at the beginning of intake and pump strokes can be improved, while still permitting the ICV to control volumetric flow.

FIG. **1** is a cross-sectional diagram of an example of a system **100** for fluid delivery. In some embodiments, the system **100** can be part of a pumping mechanism. The system **100** includes an example ICV **200**. In some embodiments, the ICV **200** can be used as a fluid control device.

The system **100** includes an outer housing **102**. A camshaft **104** rotates within the outer housing **102**. In some embodiments, the camshaft **104** can be rotated in synchronicity with a pumping mechanism. A cam follower **106** includes a roller **108**, a bushing **110**, and a bias plate **112**. The bias plate **112** is urged away from a valve housing **202** of the ICV **200** by a compliant member **120** (e.g., a spring) to urge the cam follower **106** into contact with the camshaft **104**. As the camshaft **104** rotates, the cam follower **106** is urged to move reciprocally (e.g., up and down in the illustrated example).

The bias plate **112** is removably coupled to a distal end **212** of a plunger **210** of the ICV **200**. The plunger **210** is disposed within a plunger cavity **204** defined within the valve housing **202**. The plunger **210** is configured to be urged in reciprocal axial movement within the plunger cavity **204** by the bias plate **112** as the cam follower **106** moves. In some embodiments, a seal may be disposed between a portion of the plunger **210** and the plunger cavity **204**. In some embodiments, the plunger may be configured to be urged to move axially by an electromagnetic actuator (e.g., a solenoid, an electric motor) or some other form of mechanical actuator (e.g., a linkage connected to a crankshaft).

FIG. **2** is an enlarged cross-sectional diagram of the example inlet control valve (ICV) **200**, the bias member **120**, and the bias plate **112** of FIG. **1**. The ICV **200** also includes a valve **220** that includes a shaft **222** with a stopper **224** at one end. In the illustrated example, the shaft **222** has a smaller cross section (e.g., diameter) than the stopper **224**.

A shaft cavity **216** is defined within the plunger **210** at a proximal end **214**, between an enclosed end **215***a* and an open end **215***b*. The shaft cavity **216** is sized to accommodate the shaft **222** such that the shaft **222** can move axially within the shaft cavity **216**. The shaft cavity **216** is formed to be substantially aligned with (e.g., parallel to) the plunger cavity **214**, such that the axial movement of the shaft **222** is substantially aligned with (e.g., parallel to) the axial movement of the plunger **210**.

The ICV **200** includes a stopper plate **230**. The stopper plate **230** defines a valve cavity **232** having a portion **234** sized to partly accommodate the stopper **224** (e.g., having a relatively large cross section) and another portion **236** differently sized to accommodate a portion of the shaft **222** (e.g., having a relatively smaller cross section than the portion **234**). The stopper plate **230** also defines a fluid passage **238** extending through the body of the stopper plate **230**. In some embodiments, the fluid passage **238** can be a portion of the valve cavity **232** (e.g., a gap around the stopper **224** and the shaft **222**).

The valve **220** is arranged to controllably permit and block (e.g., stop, prevent) a fluid circuit defined in a valve head **250**. It should be noted that any references to the valve **220** blocking, stopping, closing, preventing flow are to be understood as being practical within typical mechanical capabilities and manufacturing tolerances (e.g., blocking the fluid circuit can include substantially blocking the fluid circuit). The fluid circuit extends from an inlet **252**, to a chamber **254**, to an outlet **256**. The stopper **224** is disposed within the chamber **254** to controllably open and close the fluid connection between the inlet **252** and the chamber **254**. The stopper **224** is configured to move axially to a first position in which the stopper **224** at least partly contacts a seat **258** of the valve head **250** and substantially blocks fluid from flowing from the inlet **252** to the chamber **254**. As the stopper **224** is moved axially away from the seat **258**, a fluid (e.g., fuel) is able to flow from the inlet **252** to the chamber

254. Fluid in the chamber **254** is able to flow the shaft cavity **216** as well as the outlet **256**, as will be described in more detail below in reference to FIGS. **3**A-**3**E.

FIGS. **3**A-**3**E are further enlarged cross-sectional diagrams of the example inlet control valve (ICV) **200** of FIGS. **1** and **2** at various stages of an operational cycle. The housing **202** has been omitted from FIGS. **3**A-**3**E for ease of viewing.

Referring first to FIG. **3**A, the ICV **200** is shown in the same configuration as in FIGS. **1** and **2**. In the illustrated example, the stopper **224** is in a first position in which the stopper **224** at least partly contacts the seat **258** of the valve head **250** and substantially blocks fluid from flowing from the inlet **252** to the chamber **254**.

Referring now to FIG. **3**B, the plunger **210** is moved axially away from the stopper plate **230** (e.g., by movement of the example cam follower **106**) as indicated by arrow **310**. Fluid occupies the shaft cavity **216**, between the plunger **210** and the shaft **222**. As the plunger **210** moves axially away from the stopper plate **230**, the pressure of the fluid in the shaft cavity **216** decreases and draws the valve **220** axially in the same direction as the plunger **210**, as indicated by arrow **312**. Viscous frictional forces of the fluid in the shaft cavity **216** also contribute to drawing the valve **220** in the same direction as the plunger **210**.

As the valve **220** moves axially, the stopper **224** moves away from the seat **258**, unblocking the inlet **252** to allow fluid to flow through the inlet **252** into the chamber **254**. A portion of the fluid flows to and out through the outlet **256**, and a portion of the fluid flows to the fluid passage **238**.

Referring now to FIG. **3**C, the plunger **210** is moved axially further away from the stopper plate **230**. The valve **220** is shown at a fully open position in which the stopper **224** is in contact with a hard stop **320** defined at the junction between the portion **234** and the portion **236**. As such, the stopper **224** is stopped from axially following the plunger **210**.

As the plunger **210** continues to move axially, the amount of open space within the shaft cavity **216** between the shaft **222** and the plunger **210** increases. Fluid from the fluid passage **238** is drawn into the shaft cavity **216** along a lateral gap **330** defined between the shaft **222** and the wall of the shaft cavity **216**. For example, the shaft **222** can be formed with a predefined cross-section that is smaller than the predefined cross-section of the shaft cavity **216**, such that the shaft **222** fits within the shaft cavity **216** with a predefined loose tolerance that allows fluid to pass.

The gap **330** provides a physical restriction that reduces the rate of fluid flow between the fluid passage **238** and the shaft cavity **216**. This restriction and reduced rate of flow through the gap **330** provides a fluid damping function between the movement of the plunger **210** and the movement of the valve **220**. For example, the valve **220** will follow the plunger **210**, albeit with lesser speed and force than that of the plunger **210**.

Referring now to FIG. **3**D, the plunger **210** is moved axially toward the stopper plate **230** (e.g., by movement of the example cam follower **106**) as indicated by arrow **340**. Fluid occupies the shaft cavity **216**, between the plunger **210** and the shaft **222**. As the plunger **210** moves axially toward the stopper plate **230**, the pressure of the fluid in the shaft cavity **216** increases and urges the valve **220** axially in the same direction as the plunger **210**, as indicated by arrow **342**. Viscous frictional forces of the fluid in the shaft cavity **216** also contribute to urging the valve **220** in the same direction as the plunger **210**.

Referring now to FIG. **3**E, the plunger **210** is moved axially further toward the stopper plate **230**. The valve **220** is shown at a fully seated position in which the stopper **224** is in contact with the seat **258** defined at the junction between the portion **234** and the portion **236**. As such, the stopper **224** is stopped from axially following the plunger **210**.

As the plunger **210** continues to move axially, the amount of open space within the shaft cavity **216** between the shaft **222** and the plunger **210** decreases. Fluid in the shaft cavity **216** is urged out of the shaft cavity **216** along the lateral gap **330** toward the fluid passage **238**, into the chamber **254**, and out the outlet **256**. Backflow of the fluid to the inlet **252** is prevented by the valve **220**, which is seated against the seat **258**.

As was discussed above, the valve **220** and the plunger **210** are linked hydraulically, such that the valve **220** at least partly follows the plunger **210** axially as the plunger **210** is moved axially. Fluid leakage along the gap **330** provides a damping effect in the movement of the valve **220** relative to the plunger **210**. In some embodiments, the damping effect can soften impacts when the stopper **224** contacts the seat **258** and/or the hard stop **320**. In some embodiments, the damping effect can reduce the occurrence of fluid cavitation. For example, when localized pressures of a liquid decline to some point below the saturated vapor pressure, bubbles can form. These bubbles can subsequently implode and cause shockwaves that can incrementally damage nearby mechanical parts. The damping effect of the valve **220** reduces the acceleration of the valve **220** through the surrounding fluids, thereby reducing the amount of localized depressurization of the fluid and reducing or eliminating the occurrence of cavitation that can happen as a result.

FIG. **4** is flow chart that shows an example of a process **400** for controlling fluid flow using an example inlet control valve, such as the example ICV **200** of FIGS. **1**-**3**E.

At **410**, a stopper at a first end of a shaft of a valve at a first position blocks a fluid circuit between a fluid inlet to a fluid outlet. For example, FIG. **3**A shows the example stopper **224** blocking the inlet **252** from the chamber **254** and the outlet **256** at the seat **258**.

At **420**, a plunger moves axially within a plunger cavity from a first plunger position toward a second plunger position, wherein the shaft is partly arranged within a shaft cavity defined within the plunger between an enclosed end and an open end. For example, FIG. **3**B shows the example plunger **210** moving axially away from the stopper plate **230**, and the shaft **222** is partly disposed within the shaft cavity **216**, which as shown in FIG. **2**, extends between the enclosed end **215***a* and the open end **215***b*.

At **430**, fluid pressure of a fluid within the shaft cavity between the shaft and the plunger is reduced by movement of the plunger toward the second plunger position. For example, in FIG. **3**B, the pressure of fluid occupying the example shaft cavity **216** will drop as the example plunger **210** moves away from the example valve **220**.

At **440**, axial movement of the shaft within the shaft cavity from a first valve position toward a second valve position is urged by the reduced fluid pressure. For example, the shaft **222** of the example valve **220** is drawn away from the position shown in FIG. **3**A, toward the positions shown in FIGS. **3**B and **3**C. In some embodiments, viscous frictional forces of the fluid in the shaft cavity **216** also urge the valve **220** to move in the same direction as the plunger **210**.

At **450** the fluid circuit is unblocked by the stopper based on axial movement of the shaft. For example, referring to FIGS. **3**B and **3**C, the stopper **224** moves away from the seat **258**, allowing fluid to flow from the inlet **252** to the chamber **254** and the outlet **256**.

In some implementations, the process **400** can also include flowing fluid from the open end toward the enclosed end between the shaft and an inner wall of the shaft cavity, restoring fluid pressure within the shaft cavity between the shaft and the plunger, and stopping movement of the shaft relative to the plunger. For example, FIG. **3**C shows that fluid can flow along the gap from the open end **215***b* toward the enclosed end **215***a*. This flow can rebalance the fluid pressures being exerted on the top side (e.g., in the chamber **254** upon the stopper **224**) and the bottom side (e.g., in the shaft chamber **216** upon the shaft **222**) of the valve **220**. With the pressures rebalanced, the motion of the valve **220** relative to the plunger **210** will substantially stop.

The process **400** can also include moving the plunger axially within the plunger cavity toward the first plunger position, increasing, by movement of the plunger toward the first position, fluid pressure within the shaft cavity between the shaft and the plunger, urging, by the increased fluid pressure, axial movement of the shaft within the shaft cavity toward the first valve position, and blocking, by the stopper, the fluid circuit. For example, FIG. **3**D shows the plunger **210** moving axially toward the stopper plate **230**. Relative motion of the plunger and the valve **220** can cause the pressure of the fluid in the shaft cavity **216** to increase and urge movement of the shaft **222** of the valve **220** toward the stop **258**. In FIG. **3**E, the stopper **224** of the valve **220** has been moved into contact with the stop **258**, substantially blocking the fluid connection between the inlet **252** and the chamber **254**.

In some implementations, the process **400** can also include flowing fluid from the shaft cavity toward the open end between the shaft and an inner wall of the shaft cavity, restoring fluid pressure within the shaft cavity between the shaft and the plunger, and stopping movement of the shaft relative to the plunger. For example, FIG. **3**E shows that fluid can flow along the gap **330** from the shaft cavity **216** toward the open end **215***b*.

In some implementations, the process **400** can also include urging, by a biasing force provided by a compliant member, movement of the valve toward the first valve position, wherein the reduced fluid pressure is sufficient to overcome the biasing force. For example, the ICV **200** can include a spring, magnet, elastic member, or any other appropriate source of biasing force between the stopper **224** and the hard stop **320**, or within the shaft chamber **216** between the enclosed end **215***a* and the shaft **222**, in which the spring is configured to urge the stopper **224** away from the hard stop **320** and toward the seat **258**. In such examples, the valve **220** would open the inlet **252** to the chamber **254** only when hydraulic forces caused by the relative motion of the plunger **210** and the shaft **222** were large enough to overcome the biasing force of the spring.

Although a few implementations have been described in detail above, other modifications are possible. For example, the logic flows depicted in the figures do not require the particular order shown, or sequential order, to achieve desirable results. In addition, other steps may be provided, or steps may be eliminated, from the described flows, and other components may be added to, or removed from, the described systems. Accordingly, other implementations are within the scope of the following claims.

What is claimed is:

1. A fluid control device comprising:
- a housing defining a plunger cavity in fluid communication with a fluid inlet and a fluid outlet;
- a valve comprising:
  - a shaft having a first end and a second end; and
  - a stopper at the first end, configured to block a fluid circuit between the fluid inlet and the fluid outlet in a first configuration of the inlet control valve and connect the fluid circuit in a second configuration of the inlet control valve; and
- a plunger configured for axial movement within the plunger cavity, defining a shaft cavity having an inner wall extending from an enclosed end to an open end in fluid communication with the fluid outlet, and configured to accommodate axial movement of the shaft within the shaft cavity.

2. The fluid control device of claim **1**, wherein the shaft and the inner wall define a fluid passage from the open end to the enclosed end.

3. The fluid control device of claim **2**, wherein the shaft cavity and the shaft are configured such that the fluid passage has a predetermined cross-section.

4. The fluid control device of claim **1**, further comprising a biasing member configured to urge the valve toward the first configuration.

5. The fluid control device of claim **1**, further comprising a fluid seal between the plunger and a plunger cavity wall of the plunger cavity, wherein the seal defines a portion of the plunger cavity.

6. The fluid control device of claim **1**, further comprising an actuator configured to urge movement of the inlet control valve between the first configuration and the second configuration.

7. The fluid control device of claim **6**, wherein the actuator comprises a cam follower coupled to the plunger and configured to urge reciprocal axial movement of the plunger in response to rotation of a cam.

8. The fluid control device of claim **6**, wherein the actuator comprises a linkage connected to a crankshaft.

9. The fluid actuator of claim **6**, wherein the actuator is one of an electromagnetic solenoid, an electromagnetic servo, or an electromagnetic motor coupled to the plunger and configured to urge reciprocal axial movement of the plunger in response to an electrical activation signal.

10. A method of fluid control comprising:
- blocking, by a stopper at a first end of a shaft of a valve, a fluid circuit between a fluid inlet to a fluid outlet, wherein the valve is at a first position;
- moving a plunger axially within a plunger cavity from a first plunger position toward a second plunger position, wherein the shaft is arranged within a shaft cavity defined within the plunger between an enclosed end and an open end;
- reducing, by movement of the plunger toward the second plunger position, fluid pressure of a fluid within the shaft cavity between the shaft and the plunger;
- urging, by the reduced fluid pressure, axial movement of the shaft within the shaft cavity from a first valve position toward a second valve position; and
- unblocking, by the stopper based on axial movement of the shaft, the fluid circuit.

11. The method of claim **10**, further comprising:
- flowing fluid from the open end toward the enclosed end between the shaft and an inner wall of the shaft cavity;
- restoring fluid pressure within the shaft cavity between the shaft and the plunger; and
- stopping movement of the shaft relative to the plunger.

12. The method of claim 10, further comprising:
moving the plunger axially within the plunger cavity toward the first plunger position;
increasing, by movement of the plunger toward the first position, fluid pressure within the shaft cavity between the shaft and the plunger;
urging, by the increased fluid pressure, axial movement of the shaft within the shaft cavity toward the first valve position; and
blocking, by the stopper, the fluid circuit.

13. The method of claim 12, further comprising:
flowing fluid from the shaft cavity toward the open end between the shaft and an inner wall of the shaft cavity;
restoring fluid pressure within the shaft cavity between the shaft and the plunger; and
stopping movement of the shaft relative to the plunger.

14. The method of claim 10, further comprising urging, by a biasing force provided by a compliant member, movement of the valve toward the first valve position, wherein the reduced fluid pressure is sufficient to overcome the biasing force.

15. An engine system comprising:
a combustion chamber;
a camshaft;
a fuel rail; and
a fluid control device comprising:
a housing defining a fluid inlet in fluid communication with the fuel rail;
a fluid outlet in fluid communication with the combustion chamber and the plunger cavity;
a valve comprising:
a shaft having a first end and a second end; and
a stopper at the first end, configured to substantially block fluid flow from the fluid inlet to the fluid outlet in a first configuration of the inlet control valve and allow fluid flow from the fluid inlet to the fluid outlet in a second configuration of the inlet control valve; and
a plunger configured to follow the camshaft and move axially within the plunger cavity, the plunger defining a shaft cavity having an inner wall extending from an enclosed end to an open end in fluid communication with the fluid outlet, and configured to accommodate axial movement of the shaft within the shaft cavity.

16. The engine system of claim 15, wherein the shaft and the inner wall define a fluid passage from the open end to the enclosed end.

17. The engine system of claim 16, wherein the shaft cavity and the shaft are configured such that the fluid passage has a predetermined cross-section.

18. The engine system of claim 15, further comprising a biasing member configured to urge the valve toward the first configuration.

19. The engine system of claim 15, further comprising a fluid seal between the plunger and a plunger cavity wall of the plunger cavity, wherein the seal defines a portion of the plunger cavity.

20. The engine system of claim 15, further comprising an actuator configured to urge movement of the inlet control valve between the first configuration and the second configuration.

21. The engine system of claim 20, wherein the actuator comprises a cam follower coupled to the plunger and configured to urge reciprocal axial movement of the plunger in response to rotation of a cam.

22. The engine system of claim 20, wherein the actuator comprises a linkage connected to a crankshaft.

23. The engine system of claim 20, wherein the actuator is one of an electromagnetic solenoid, an electromagnetic servo, or an electromagnetic motor coupled to the plunger and configured to urge reciprocal axial movement of the plunger in response to an electrical activation signal.

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